The Relationship Between Patterns in Flying Adult Insect Assemblages and Vegetation Structure in Wetlands of Ohio and Texas[1]

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ABSTRACT. The success of compensatory wetland replacement is frequently judged on the basis of percent vegetation cover. Measuring percent cover of wetland species, or the survival of planted species, especially only one or two years after construction seems tautological. Aquatic insects have been used for many years as indicators of ecosystem integrity and may be useful as an integrative wetland assessment tool. This study was initiated to determine if adult insect assemblages could be used to differentiate between wetlands and uplands, and to identify site characteristics, especially vegetation, related to patterns in insect assemblages. We collected adult insect assemblages using light traps at wetlands in northeastern Ohio and southeastern Texas. We also measured properties of wetland vegetation structure and composition around the light traps and performed indirect gradient analysis. We found that ordinations of flying nocturnal insect assemblages generally separated upland from wetland sites and that insect ordination patterns were related to vegetation density and predominant vegetation growth forms such as vines, herbs, shrubs and trees.

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INTRODUCTION

Thousands of acres of wetlands are lost each year in the United States due to filling, diking, and development. Twenty-two states, including Ohio and Texas, have lost more than 50% of their wetland area during the period from 1780 to 1980 (Dahl 1990). Notwithstanding this dramatic loss during this 200 year period, wetlands continue to be destroyed. Since current federal policy calls for no net loss of wetlands, when wetlands are destroyed, creation of new wetlands or restoration of existing ones is required.

Wetlands are valued because they perform a variety of beneficial functions, such as nutrient transformation, hydrologic desynchronization, and pollutant and sediment retention (Kusler and Kentula 1994; Mitsch and Gosselink 1986; Whigham and others 1988). Replacement wetlands are intended to replace not only lost acreage but also lost ecological functions. The success of wetland replacement, however, is often evaluated by measuring acreage, plant survival or vegetation cover (Kusler and Kentula 1994). Wetland designers often directly manipulate vegetation composition and density. Therefore, assessing the success of wetland replacement projects based on criteria the designers specifically installed, and presumably selected for maximum success, seems tautological. Direct measurement of wetland function is impractical within a regulatory framework (Smith and others 1995). Wetland assessment techniques currently employed or under development generally use structural aspects of wetlands and the surrounding landscape to indicate wetland function. Examples include the Wetland Evaluation Technique (Adamus and others 1991) and the Hydrogeomorphic Method (Smith and others 1995). Simenstad and Thom (1996) caution that the assumption that wetland "function follows form," may be equivocal due to the high degree of natural variability and the lack of understanding of long-term trends in wetland processes. Most methods rely on the presence of certain structural or compositional features in the wetland and surrounding landscape to predict whether particular functions are present in the wetland being assessed. It is important to note that this link between structure and composition, and wetland function, while perhaps intuitive, has not been empirically established for many wetland functions.

Finding a group of organisms sensitive to the ecological forces that create and maintain wetland ecosystems, and that are not directly manipulated by wetland designers, would allow wetland assessment with fewer inherent biases. The ecological requirements of many insects are well known. Indeed, the presence of certain insect groups has been used to assess the ecological integrity of terrestrial ecosystems (Kremen and others 1993), streams and rivers (Hilsenhoff 1982; Karr 1998, 1991; Plafkin and others 1989; Ohio EPA 1988). Surprisingly, insects are rarely used to assess wetland integrity, perhaps due to difficulties associated with sampling. For example, large numbers of grab samples or cores may be necessary to represent spatial variability present at some sites (Minshall 1988; Streever and others 1995). In addition, sampling may destroy fragile wetland vegetation (Olson and others 1995). Sampling insects with light traps overcomes many of these problems.

This study was initiated to determine if adult insect assemblages captured by light traps could be used to differentiate between wetlands and uplands, and to identify factors related to observed patterns in the insect assemblages. If predictable patterns in adult insects assemblages found in various wetland types can be associated with characteristics describing various levels of wetland integrity, then a wetland assessment tool based on these easily sampled insects might be developed.

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METHODS

During a 7-day period in August, 1994 we visited 8 sites in northeastern Ohio and during a 3-day period in 1995 we sampled 9 sites at a single location (Roy E. Larsen Sandyland Sanctuary/Big Thicket National Preserve) in Texas (Fig. 1). Sites were located within areas, both private and public, managed for conservation, except for two Ohio mitigation sites. At all Ohio sites we established at least two sampling locations, generally one in a wetland and one in an adjacent upland. We established only upland locations at Geneva State Park, and only wetland locations at the Winous Point Shooting Club. Texas sample sites were either entirely upland or entirely wetland, except for site T-1. At most sample locations we collected data on plant community structure and composition.

Plant Community Sampling

At selected sample locations, composition and vertical structure of the vegetation was measured using a modified line-intercept method developed for this project (Tables 1 and 2). Due to time constraints, it was not possible to survey vegetation at all sample locations. Four 30-m long line transects were established along cardinal directions with the light trap at the center. At two meter intervals along each transect we sampled the vertical distribution of vegetation to a height of 2.0 m using a graduated pole. At 1.0 cm intervals we recorded the plant species and growth form (vine, herb, shrub, or tree). In all wetlands the sampling pole was held firm to the substrate, thus in inundated wetlands we measured water depth and vegetation height.

We calculated the total number of plant-pole intersections (a measure of vegetation density), average canopy height (cm), and the number of plant-pole intersections occupied by each species for each sample location. We considered dominant plant species to be cumulatively responsible for 75% or more of the plant-pole intersections at each sample location. In this paper we present vegetation data from 6 (of the 14 sample locations) Northeast Ohio sites and 5 (of the 9) southeast Texas sites.

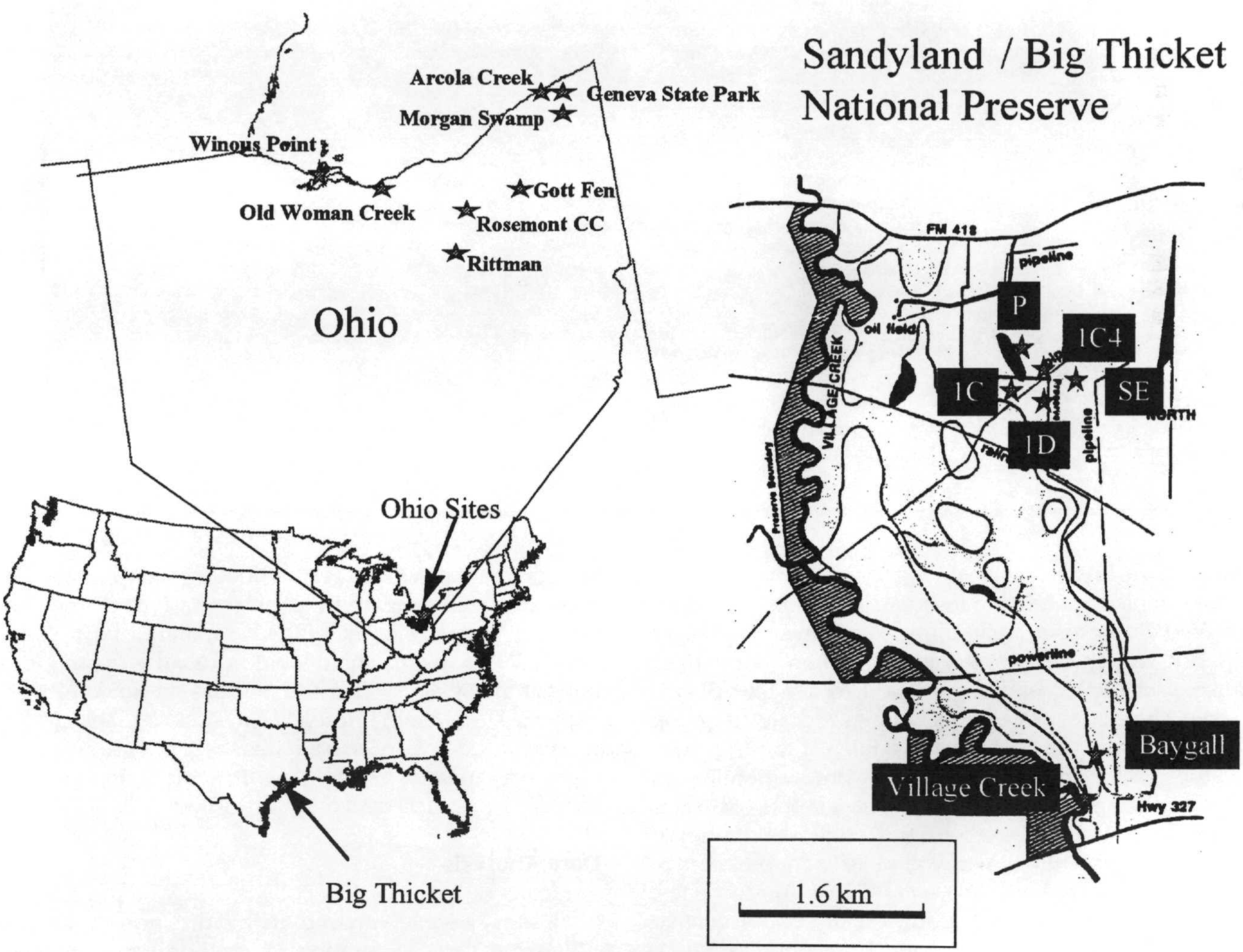

FIGURE 1. Location and ownership of study sites. Ohio sites were Arcola Creek (The Nature Conservancy, TNC), Geneva State Park (Ohio Dept of Natural Resources, ODNR), Gott Fen (ODNR), Morgan Swamp (TNC), Old Woman Creek, National Estuarine Research Reserve (ODNR), Rittman (private), Rosemont Country Club (private), and Winous Point Shooting Club (private). Texas sites were located on the Roy E. Larsen Sandyland Sanctuary (TNC: Village Creek, Baygall, P = Pond, 1C = Stream 1C, 1C4 = Upland 1C4, SE = Upland SE, 1D = Pond Upland 1D) or within the Big Thicket National Preserve. Note that the location of the Big Thicket Pond and the TI Wetland are not shown.

TABLE 1

Vegetation survey for 6 northeast Ohio light trap locations. Shown are site names, description, number of plant taxa appearing in sample, dominant plant taxa and cumulative proportion of plant-pole intersections, average vegetation height (cm), number of plant-pole intersections and proportion of plant-pole intersections for 4 growth forms (V = vines, H = herbs, S = shrubs, and T = trees).

Site description	Number of plant taxa	Dominant plant taxa	Avg. veg. ht. (cm)	Plant-pole int.	Growth form %V	%H	%S	%T
Arcola Creek Lake Erie drowned river mouth, emergent marsh	12	*Sagittaria latifolia* (26.3) *Sparganium americanum* (52.3) *Polygonum* sp. (77.6)	84.1	331	0.0	100.0	0.0	0.0
Gott Fen Inland fen, shrub dominated	24	*Potentilla fruticosa* (53.2) *Carex* sp. (69.9) *Carex x stipata* (84.0)	40.2	1,554	0.0	41.6	58.4	0.0
Old Woman Creek, (River) Lake Erie drowned river mouth, emergent marsh	7	*Scirpus fluviatilis* (52.2) *Phalaris arundinacea* (88.7)	83.0	647	0.0	97.2	2.8	0.0
Rittman Replacement wetland, emergent and scrub-shrub	18	*Phalaris arundinacea* (53.5) *Viburnum dentatum* (64.7) *Juncus effusus* (75.8)	64.3	1,360	0.0	77.6	22.2	0.2
Rosemont CC Replacement wetland, emergent and scrub-shrub	41	*Lythrum salicaria* (15.3) *Phalaris arundinacea* (28.4) *Phragmites communis* (35.8) *Cornus racemosa* (42.2) *Scirpus validus* (47.8) *Salix nigra* (53.2) *Eupatorium perfoliatum* (57.5) *Leersia oryzoides* (61.6) *Poa* sp. (65.7) *Prunus serotina* (68.8) *Typha x glauca* (71.9) *Cornus florida* (74.2) *Parthenocisus quinquefolia* (76.5)	76.1	430	0.0	78.2	13.1	8.7
Winous Point Lake Erie floating leaved and emergent marsh, diked	4	*Pontedaria cordata* (45.3) *Nelumbo lutea* (70.7) *Lemna minor* (96.0)	30.4	138	0.0	100.0	0.0	0.0

Insect Sampling

We sampled adult flying insects using portable, battery powered fluorescent light traps. We constructed light traps by suspending an 8-watt fluorescent lamp from transparent plastic baffles attached to a white plastic bucket. These low-power lights minimized the attraction of insects not in the immediate vicinity of the trap. Uncovered (visible from above) traps were suspended on poles approximately 1.0 m above the ground (or water surface in inundated wetlands). To kill and preserve specimens, light traps were filled to a depth of approximately 2.0 cm with 70% (v/v) ETOH. At most sites, light trap collections were made on three consecutive evenings and traps were operated from dusk to dawn. Time constraints, equipment failure and rainy weather prevented us from making successful collections on 3 consecutive nights at Arcola Creek, Geneva State Park, and Morgan Swamp in northeast Ohio, and at the BT and TI Wetland sites in southeastern Texas. At all Ohio sites except the Winous Point Shooting Club and Geneva State Park we operated one trap in the wetland, and one trap in an adjacent upland, separated by approximately 70 to 100 m. There were no nearby upland locations at the Winous Point site, and no wetlands near the Geneva site. The Winous Point site was selected to represent Lake Erie coastal marshes; the Geneva site represents uplands on the Lake Erie plain. Insects were identified to order, counted, and stored in 70% ETOH.

Data Analysis

Means of insect orders collected at wetland and upland sites were compared using the non-parametric Wilcoxon Test. Detrended Correspondence Analysis (DCA) was used to visualize patterns of insect presence or absence and abundance within the site by insect order data matrix using PC-ORD (McCune and Medford 1997). An indirect gradient analysis was performed by correlating DCA axis scores for insect assemblages with

TABLE 2

Vegetation survey for five light trap locations in the Big Thicket National Preserve, Texas. Shown are site names, description, number of plant taxa appearing in sample, dominant plant taxa and cumulative proportion of plant-pole intersections, average vegetation height (cm), number of plant pole intersections and proportion of plant-pole intersections for 4 growth forms (V = vines, H = herbs, S = shrubs, and T = trees).

Site description	Number of plant taxa	Dominant plant taxa	Avg. veg. ht. (cm)	Plant-pole int.	Growth form % V	% H	% S	% T
Baygall Scrub-shrub	10	*Persea borbonia* (39.3) *Sphagnum* sp. (72.5) *Nyssa sylvatica* (80.3)	23.2	276	1.1	45.2	4.0	49.7
Upland 1-D Forested upland	17	*Ilex vomitoria* (42) *Carya* sp. (nr *aquatica*) (54.4) *Callicarpa americana* (64.0) *Quercus stellata* (72.4) *Cornus florida* (76.6)	34.7	408	0.0	14.2	57.5	28.3
Upland 1-C Forested upland	11	*Ilex vomitoria* (38.2) *Cornus florida* (75.9)	17.7	377	0.0	53.7	2.1	44.2
TI Wetland Sedge meadow	11	*Eleocharis* sp. (81.3)	18.9	782	0.0	89.9	3.0	7.1
Village Creek Cypress-dominated, forested ravine bottomland	17	*Taxodium distichum* (40.0) *Lysimachia radicans* (55.9) *Alternathera philoxeroides* (70.3) *Poa* sp. (77.9)	17.7	377	0.0	53.7	2.1	44.2

plant community variables, one variable at a time.

RESULTS

Vegetation Results

Our vegetation sampling method was not designed to represent the species composition of the entire wetland sampled. Rather our goal was to characterize the structure and composition of the vegetation in the immediate vicinity of each light trap. Vegetation at the sampled locations differed in both structure and composition (Tables 1 and 2), and sample protocols seemed to adequately describe vegetation features. For example, a floating-leaved marsh (Winous Point; Table 1) and a sedge meadow (TI Wetland, Table 2) had few dominant plant species, low average canopy height, and were dominated by low-growing herbaceous vegetation. Sites dominated by emergent plants (for example, *Scirpus fluviatilis, Phalaris arundinacea* and *Lythrum salicaria*) in sites such as Old Woman Creek, Rosemont Country Club and Rittman (Table 1) tended to have higher average canopy heights and higher proportions of plant-pole interactions (Tables 1 and 2). Shrub dominated and forested sites (Gott Fen, Rittman; Table 1, Baygall Upland 1-D and 1-C and Village Creek; Table 2), in contrast, tended to have intermediate average canopy heights and high proportions of plant-pole intersections for shrub and tree species. Since we only sampled vegetation to a height of 2.0 m, the structure and stratification of forested sites is obviously not well described by this method. Aside from this limitation, the method captured enough variability to determine differences in plan community structure and composition.

Insect Results

Thirty-four successful light trap collections made at 8 Ohio sites resulted in the collection of 76,330 insects representing 11 orders (Table 3). The number of insects collected was highly variable both between sites and at a single location. The number of individuals collected at Ohio sites ranged from 16 (Arcola Creek, 15 August 1994), to 23,296 individuals (Winous Point, 18 August 1994). These disparities were mostly due to large numbers of Ephemeropterans collected at Winous Point (a Lake Erie coastal wetland) in traps set at lakeside and in an adjacent diked coastal marsh. We did not note such large numbers of Ephemeropterans at the other Lake Erie sites, Old Woman Creek and Arcola Creek. Interestingly, the number of individuals collected at Gott Fen on 3 successive evenings varied over three orders of magnitude.

Five orders, Diptera (N = 47,576), Ephemeroptera (n = 22,240), Coleoptera (n = 1,834), Trichoptera (n = 1,561) and Lepidoptera (n = 1,280) accounted for over 97% of all insects collected. The wholly aquatic orders (Trichoptera and Ephemeroptera) alone were responsible for more than 30% of the insects collected. Wetland and upland comparisons showed that more Ephemeroptera and Trichoptera were found at wetland than upland sites (Table 4).

While our Ohio samples were taken throughout northeast Ohio, Texas samples were taken from a much smaller area of only several square kilometers in the Sandyland Preserve and the Big Thicket National Preserve (Fig. 1). Twenty-three light trap collections resulted in 30,182 individuals from 16 orders (Table 5).

TABLE 3

Light trap collections from 8 study sites in northeast Ohio. Shown are study sites, upland (U) and wetland (W) collection locations, date, number of individuals for each insect order, total, and proportion of individuals in each order.

Site	Type	Date (Aug 94)	Diptera	Ephemeroptera	Coleoptera	Lepidoptera	Trichoptera	Homoptera	Hemiptera	Hymenoptera	Orthoptera	Neuroptera	Odonata	Total
Arcola Creek	U	15	29		1	17	13							60
	U	19	213		40	98	145	10	1	8	1			516
	W	15	15								1			16
Geneva State Park	U	15	42			22	1							65
	U	19	42	2	32	17	8	23	4	4	4			136
Gott Fen	W	12	228	14	15	62	18	43	3	34				417
	W	13	771	5	51	110	128	188	39	57				1,349
	W	14	7	6	2	6		1	1					23
Morgan Swamp	U	15	14		1	18	1	1						35
	U	19	61		28	30		9		9				137
	W	15	22			9	1			2				34
Old Woman Creek	W	16	750	16	7	23	27	3	1	2				829
	W	17	441	37	61	51	70	10	7	7				684
	W	16	7,211	122	6	26	85	1	1	5				7,455
	W	18	320	4	41	10	9		6	17		2		409
	W	16	566	223	6	17	59	1						872
	W	17	269	98	4	30	30	6	3	2				442
	W	18	85	32		3	9	5		27				161
	U	16	302		6	42	2	62	1	2		1		418
	U	17	632	15	33	85	27	111	5	5	1	2		916
	U	18	118	1	3	7	5	9		3				146
Rittman	U	12	65		49	105	1	42	4	9	1	1		277
	U	14	80		2	89	1	4	1	5		2		184
	W	13	578		27	27	9	38	17	6				702
Rosemont CC	U	12	434		838	172	44	107	28	60	1			1,584
	U	13	126		151	11	38	8	3	7				344
	U	14	7	2	4	26	1		1					41
	W	12	206	41	86	19	91	55	24	1		1		524
	W	13	331	1	100	19	98	42	30	1	1			623
	W	14	12	24		3	2		1	1				43
Winous Point	W	18	15,510	225	25	22	65	92	5	18	3			15,965
	W	16	3,777	5,095	40	48	79	12	19					9,070
	W	17	721	7,062	141	37	250	65	178	2			1	8,457
	W	18	13,591	9,215	36	19	244	81	100	7		1	2	23,296
	Total		47,576	22,240	1,834	1,561	1,280	1,029	483	301	13	10	3	76.330
	Prop.		62.3%	29.1%	2.4%	2.1%	1.7%	1.4%	0.6%	0.4%	0.0%	0.0%	0.0%	

The number of insects collected in a single trapping event ranged from 554 individuals (Baygall, 2 June 1995) to 3,741 individuals (TI Wetland, 4 June 1996). The number of individuals was distributed more equitably among insect orders in the Texas collections than in the Ohio collections. Seven orders, Coleoptera (n = 9,785), Diptera (n = 5,948), Lepidoptera (n = 4,036), Hemiptera (n = 3,707), Homoptera (n = 3,064), Hymenoptera (n = 2,051), and Trichoptera (n = 1,257) accounted for over 98.9% of the insects collected. The wholly aquatic orders accounted for only 5.0% of the individuals in the overall collection. Several orders (Blattaria, Isoptera and Thysanoptera) were collected in Texas but not in Ohio. There was no difference in the total number of insects between wetlands and uplands in the Texas sites; however, we found that Diptera, Trichoptera, and Ephemeroptera were significantly greater in wetlands than in uplands, and the number of

TABLE 4

*Comparison of the mean number of individuals of major insect orders collected by light traps at upland and wetland sites in northeast Ohio. Major orders shown are cumulatively responsible for 95% of the total number of insects collected. Shown are the ranked orders, the location (upland or wetland), the number (n) of light traps and the mean number of individuals (+/- standard error) and the value of the Wilcoxon test statistic comparing upland and wetland collections. Significance levels are indicated by: NS = not significant; * = p<0.05; ** = p<0.01.*

Rank and order	Location	n	Mean no. ind. ± standard error	Wilcoxon/Kruskal-Wallace value for wetland/upland comparison
1. Diptera	Wetland	16	332.6 ± 69.	
	Upland	14	154.6 ± 49.1	Z = -1.58003
2. Ephemeroptera	Wetland	17	49.9 ± 18.0	
	Upland	14	14.1 ±Y 1.1	Z = -3.46459**
3. Coleoptera	Wetland	20	32.3 ± 8.7	
	Upland	14	84.9 ± 58.9	Z = -0.07014
4. Trichoptera	Wetland	20	63.7 ± 16.5	
	Upland	14	20.5 ± 10.4	Z = -2.14193*
Total	Wetland	20	3,685.5 ± 1,412.1	
	Upland	14	354.2 ± 120.8	Z = -1.90710

Hymenoptera was greater in uplands than in wetlands (Table 6).

Detrended Correspondence Analysis (DCA) (Hill 1979) was used to describe patterns of the flying insect collections. A relative abundance data matrix was constructed from the "collection event by order" data matrix and ordinated (26 segments, no down weighting). The first two DCA axis scores from ordination of the Ohio collections captured 55.6% and 2.9%, respectively, of the original data matrix variability (Fig. 2). Upland and wetland collections appeared separated on DCA axis I. Upland collections had axis I scores ranging from 0 to 99 and wetland collections ranged from 72 to 226. Notice that collections from replacement wetlands (Rittman and Rosemont CC) were scattered along DCA axis I at intermediate values, except for one sample from Rosemont CC, which plotted with the wetland collections. Ordination of the Texas light trap collections also performed reasonably well in separating wetlands and uplands (Fig. 3). The first two DCA axis scores accounted for 74.8% and 6.7%, respectively, of the original data matrix variability. Upland collections appeared at low axis I and II values and the wetland collections appeared widely scattered across axis I and at high axis II values. Two collections taken at Village Creek (a narrow slough at the toe of a forested stream bank) appeared together with the upland collections in ordination space.

We asked if there were vegetation characteristics that could help explain patterns observed in the insect assemblages. We made correlations between ordination axis scores and the vegetation characteristics measured at each site where both light trapping and vegetation sampling occurred. Significant correlation coefficients were not considered meaningful if they appeared to be influenced by a small number of outliers, as shown by graphical inspection. For the Ohio sites, we found a significant positive correlation between DCA axis I and the proportion of herbaceous vegetation, and a significant negative correlation between vegetation density (plant – pole intersections) and the proportion of shrubby vegetation (Table 7). Axis II was significantly positively correlated with the number of plant taxa (Table 7). Like Ohio, DCA axis I scores from ordinations of Texas light trap collections were significantly correlated with vegetation density (Table 7). Significant relationships existed between DCA axis II scores and the average canopy height, and between both DCA axis I and II scores and the proportion of trees in Texas sites (Table 7).

DISCUSSION

Accurate monitoring and assessment are essential to evaluate the real costs of wetland mitigation. Insects are well suited for wetland assessment for a number of reasons. Insects are ubiquitous and relatively short-lived, so their populations may quickly respond to environmental changes. Insect populations are wetland ecosystem components not directly manipulated by wetland managers. Insect's specific ecological requirements and life history traits make insect populations good indicators that specific functions are being established in replacement or restored wetlands.

To be useful, any collection method must be able to produce repeatable and interpretable results. In this study sampling flying, nocturnal insect assemblages by light trapping overcomes many problems associated with other sampling methods such as sweep netting, coring and grab sampling. Adult insects, however, are vagile and light traps only sample flying, positively phototaxic insects (Southwood 1966).

TABLE 5

Light trap collection results for 9 study sites in The Big Thicket National Preserve, TX. Shown are study sites, upland (U) and wetland (W) collection locations, date, number of individuals for each insect order, total, and proportion of individuals in each order.

Site	Type	Date (Jun 95)	Coleoptera	Diptera	Lepidoptera	Hemiptera	Homoptera	Hymenoptera	Trichoptera	Ephemeroptera	Psocoptera	Neuroptera	Plecoptera	Blattaria	Thysanoptera	Orthoptera	Isoptera	Odonata	Total
BT Pond	W	04	327	256	187	35	81	92	49		4	3	2		8	1			1,045
Baygall	W	02	98	133	176	28	56	27	33	1		2							554
	W	03	225	269	221	58	59	12	24		3	2	1						874
	W	04	302	330	101	96	80	18	37	2	4			2				1	973
Pond	W	02	578	222	148	1,313	143	41	120	20	1		1						2,587
	W	04	490	515	112	340	155	35	163	5	1								1,926
	W	03	979	347	125	518	179	55	119	7			1						2,330
Pond Upland 1D	U	02	380	321	190	113	122	109	13	3	5		3						1,259
	U	03	533	257	153	87	188	178	11	3	4		1	1		2			1,418
	U	04	357	126	95	77	96	92	2		2			1		1			849
Stream 1C	W	02	303	448	176	96	115	159	16	4	18	3		2					1,340
	W	03	458	445	158	91	266	250	19	3	8	2	2			2			1,704
	W	04	319	311	83	56	135	87	11	2	6	1	2	2					1,015
Upland 1C-4	U	02	524	216	184	79	85	96	13	2	3								1,202
	U	03	499	154	209	76	123	184	20	2	5	2		4					1,278
	U	04	233	111	79	67	70	104	7		3	1		2		1	1		679
Upland SE	U	03	244	184	277	57	46	104	6	5	4		1	1	1				930
	U	04	141	101	190	53	29	76	5	1	3			3					602
Village Creek	W	02	105	134	287	23	21	28	30	5	7	3	1						644
	W	03	420	187	223	61	36	83	26	40	1	1	3		2				1,083
	W	04	284	157	208	36	31	45	37	31	2		1	1		1			834
T1	U	04	487	245	311	54	57	132	14		5	5	1	2	1	1			1,315
	W	04	1,499	479	143	183	891	44	482	16			4						3,741
Totals			9,785	5,948	4,036	3,707	3,064	2,051	1,257	152	89	25	24	21	12	9	1	1	30,182
Prop.			32.4%	19.7%	13.4%	12.3%	10.2%	6.8%	4.2%	0.5%	0.3%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	

We identified insects to order in this study. Previous studies have demonstrated that genus- and species-level data could be used to characterize Ohio wetlands (Garono 1986; Garono and MacLean 1988; Garono and Kooser 1994) and we wondered if there were patterns at higher taxonomic levels. Order-and family-level identifications are frequently used in biotic assessments where time and resources do not permit more in-depth taxonomic identification (Hilsenhoff 1988; Chessman 1995; Anderson and Vondracek 1999).

There are advantages and disadvantages to using coarse taxonomic data. Order-level identifications minimize differences due to species substitutions across individual species' ranges and phenological differences due to different emergence periods. Even at the order level there are particular ecological requirements of certain taxa that may be useful for wetland assessments. For example, wholly aquatic orders (for example, Ephemeroptera, Trichoptera, and Plecoptera) would be expected to be more commonly encountered in wetlands than non-wetlands, a pattern evident in this study. Furthermore, we found that volunteers could reliably identify insect orders after only a few hours of training, indicating that regulators and consultants, those most often involved in assessing the success of wetland replacement, should be able to use such a technique. Hilsenhoff (1988) cautions, however, that the coarse taxonomic data should be used as a screening tool to decide where more detailed study should be performed. Therefore, the use of order-level data may impair determination of which ecological requirements or changes produce the patterns observed, due to the diversity of life histories encompassed within an order. We are not advocating the use of coarse taxonomic data as a

TABLE 6

*Comparison of the mean number of individuals of major insect orders at upland and wetland sites in Texas. Major orders shown are cumulatively responsible for 95% of the total number of insects collected. Shown are the ranked orders, the location (upland or wetland), the number (n) of light traps and the mean number of individuals (+/- standard error) and the value of the Wilcoxon test statistic comparing upland and wetland collections. Significance levels are indicated by: NS = not significant; * = p<0.05; ** = p<0.01.*

Rank and Order	Location	n	Mean No. Ind. ± Standard Error	Wilcoxon/Kruskal-Wallace value for wetland/upland comparison
1. Coleoptera	Wetland	14	456.2 ± 99.3	
	Upland	9	377.6 ± 48.2	Z = 0.03621
2. Diptera	Wetland	14	302.4 ± 35.0	
	Upland	9	190.6 ± 25.0	Z = -2.20883*
3. Lepidoptera	Wetland	14	167.7 ± 14.8	
	Upland	9	187.6 ± 25.1	Z = 0.25364
4. Hemiptera	Wetland	14	217.4 ± 94.0	
	Upland	9	73.7 ± 6.4	Z = -0.39844
5. Homoptera	Wetland	14	160.6 ± 59.1	
	Upland	9	90.7 ± 16.2	Z = -0.39831
6. Hymenoptera	Wetland	14	69.7 ± 17.3	
	Upland	9	119.4 ± 12.7	Z = 2.57177**
7. Trichoptera	Wetland	14	83.3 ± 33.1	
	Upland	9	10.1 ± 1.9	Z = -3.33460**
Total	Wetland	14	1,475.0 ± 240.1	
	Upland	9	1,059.1 ± 99.8	Z = -0.90526

replacement for more detailed study, but rather we are interested in learning if higher taxonomic groups can be used as a rapid assessment or screening tool by relatively unskilled laborers where time and resources may be limited.

Study sites in Texas and Ohio had many insect orders in common, including the most frequently encountered orders (Tables 3 and 5). We also found that numbers of Ephemeroptera and Trichoptera collected by light traps, often separated by only 75 to 100 m, were significantly greater at wetland sites than at upland sites. These results were similar to those of Jackson and Resh (1989) who used non-baited sticky traps to sample insects at

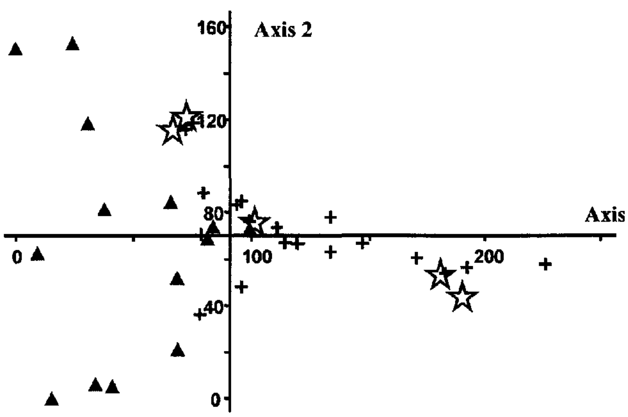

FIGURE 2. Detrended Correspondence Analysis axes I (abscissa) and II (ordinate) of an ordination of 34 light trap collections of flying adult insects made at 8 Ohio sites. Triangles are uplands, plus signs are wetlands, stars indicate replacement wetland sites. Upland sites tended to occur at low axis I values in ordination space and were characterized by dense vegetation with high proportions of shrubs. Wetland sites tended to occur at high axis I values in ordination space and were characterized by less dense plant communities with high proportions of herbaceous plants. Replacement sites tended to plot at intermediate axis I values, between upland and wetland sites. Those sites which plotted high on axis II had greater species richness and a higher proportion of trees than sites with lower axis II scores.

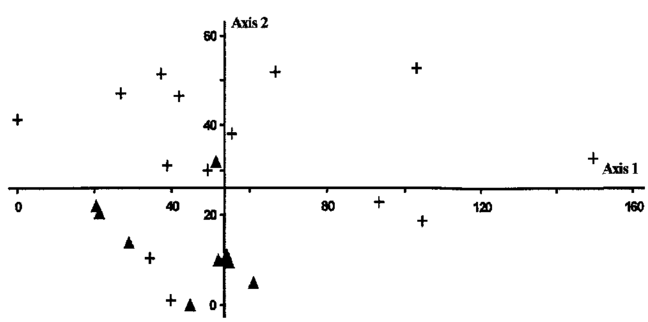

FIGURE 3. Detrended Correspondence Analysis axes I (abscissa) and II (ordinate) of an ordination of 23 light trap collections of flying insects made at 9 within the Big Thicket National Preserve, TX. Triangles are uplands and plus signs are wetlands. Sites with low axis I scores had dense vegetation and plant communities dominated by tall trees and shrubs. Sites with high axis II scores had a greater proportion of trees and vines.

TABLE 7

Pearson correlation coefficients between Detrended Correspondence Analysis axes I and II scores and vegetation measurements for ordinations of northeastern Ohio and southeastern Texas light trapped insect collections.

Vegetation variable	Ohio DCA I	Ohio DCA II	Texas DCA I	Texas DCA II
Number of plant taxa	-0.522*	0.564*	-0.239	-0.477
Average canopy height	-0.288	0.376	0.201	-0.552*
Number of dominant species	-0.201	0.570*	-0.328	-0.119
Number of plant-pole interactions	-0.641	-0.014	-0.597*	-0.491
Percent vines	N/A	N/A	-0.089	0.569*
Percent herbs	0.635*	-0.112	0.074	0.443
Percent shrubs	-0.600*	0.020	0.206	-0.651*
Percent trees	-0.200	0.578*	-0.579*	0.678*

* = $p<0.05$

varying distances from a California stream and found more aquatic insects collected at sites closer to the stream than at sites 150 m distant.

In addition to comparing key taxonomic groups at wetland and upland sites, we used ordination to examine patterns within the insect assemblages. The use of descriptive multivariate techniques for biological monitoring has been criticized because such techniques lose information and often downplay insight gained from knowledge of natural history (Karr 1998). Ordinations are descriptive statistical techniques that summarize community data (Gauch 1982) and, by necessity, this summary usually contains less information than the original data matrix. Ultimately, the utility of an ordination approach depends on the ecological insight achieved by its use. We found ordinations from Ohio and Texas sites correctly categorized most upland and wetland light trap collections (Figs. 2, 3). In previous studies, we found that light trapped insect assemblages could be used to categorize wetlands as bogs, fens, and emergent marshes in Ohio (Garono 1986; Garono and MacLean 1988; Garono and Kooser 1994).

Comparing entire insect samples of several Ohio replacement wetlands to natural wetlands showed that Ohio replacement wetlands plotted at intermediate DCA axis I scores and were not clearly distinguishable as either uplands or wetlands. This may indicate that the replacement sites are on a trajectory from upland to wetland characteristics. However, the pattern may be due to the small numbers of replacement wetlands in our study, or to the coarse taxonomic level we used. We expect that ordination of insect collections identified to family or genus may produce more distinct patterns.

Indirect gradient analysis is one method used to interpret ordination patterns, and this technique was used here to relate patterns in insect ordinations to the structure of wetland vegetation. Plant community architecture may affect evapotranspiration rates, wind velocities, and air temperatures (Wilcove 1987; Saunders and others 1991), producing microenvironments selected by insects for resting, feeding, ovipositing sites (Samways 1994), or to decrease predation (Wellborn and others 1996). We found that adult insect assemblages were related to vegetation structure (Table 7).

In summary, we conclude that light-trapped adult insect collections can be used to distinguish between some wetlands and non-wetlands. These coarse taxonomic data made it possible to compare wetland ecosystems across large geographic areas with collections made at different times. We also found that the few replacement wetlands represented in our sites appeared at intermediate positions between wetlands and uplands in ordination space. This indicates the technique may prove useful for monitoring the success of wetland restoration or replacement.

New methods of assessing wetland function are being developed. The Hydrogeomorphic Method (Smith and others 1995) includes variables that require the assessment of wetland insect populations. Our results show that light trapping and ordination may be useful techniques for comparing assessment wetlands with reference standards. Future work includes experimental manipulations of vegetation to determine if there is a predictable effect of vegetation change on insect assemblages, and sampling at replacement wetland sites before, during, and after construction.

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